Adaptive and cooperative decision-making strategies for autonomous driving in urban environments

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Abstract

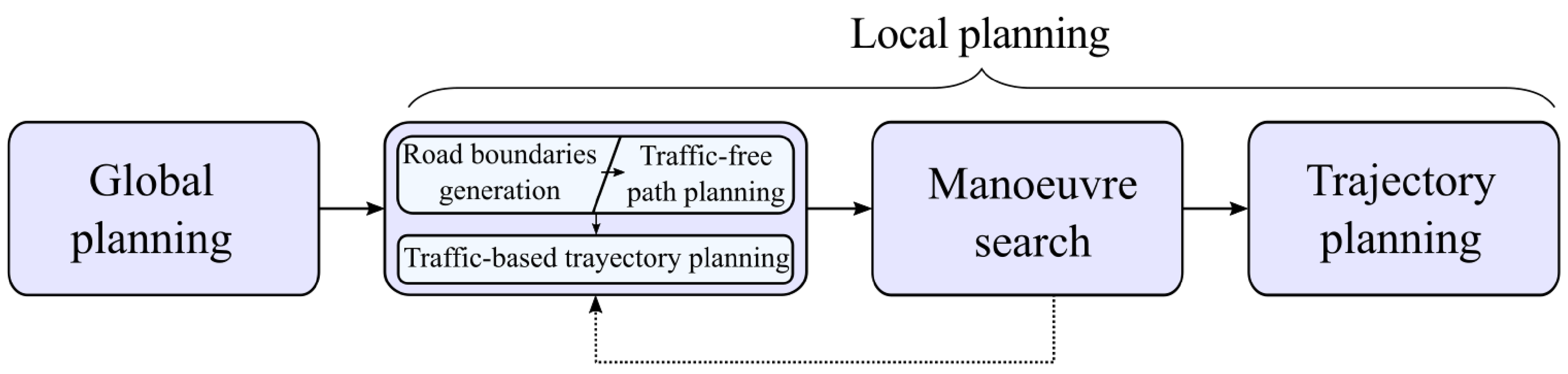
This thesis is framed within the area of intelligent control systems and automation. The main objective is the development of advanced strategies for decision making in automated vehicles, taking advantage of both the information available in the vehicle and V2X communications.

The uncertainty inherent in the different sensors and V2X communications, as well as the variability of driving scenes in urban environments, make it necessary to design and develop a context-dependent adaptive control architecture. To this end, this doctoral thesis addresses the application of risk inference and motion planning systems capable of integrating uncertainty and heterogeneity in sensory information, while structurally incorporating the possibility of learning from complex and unpredictable situations.

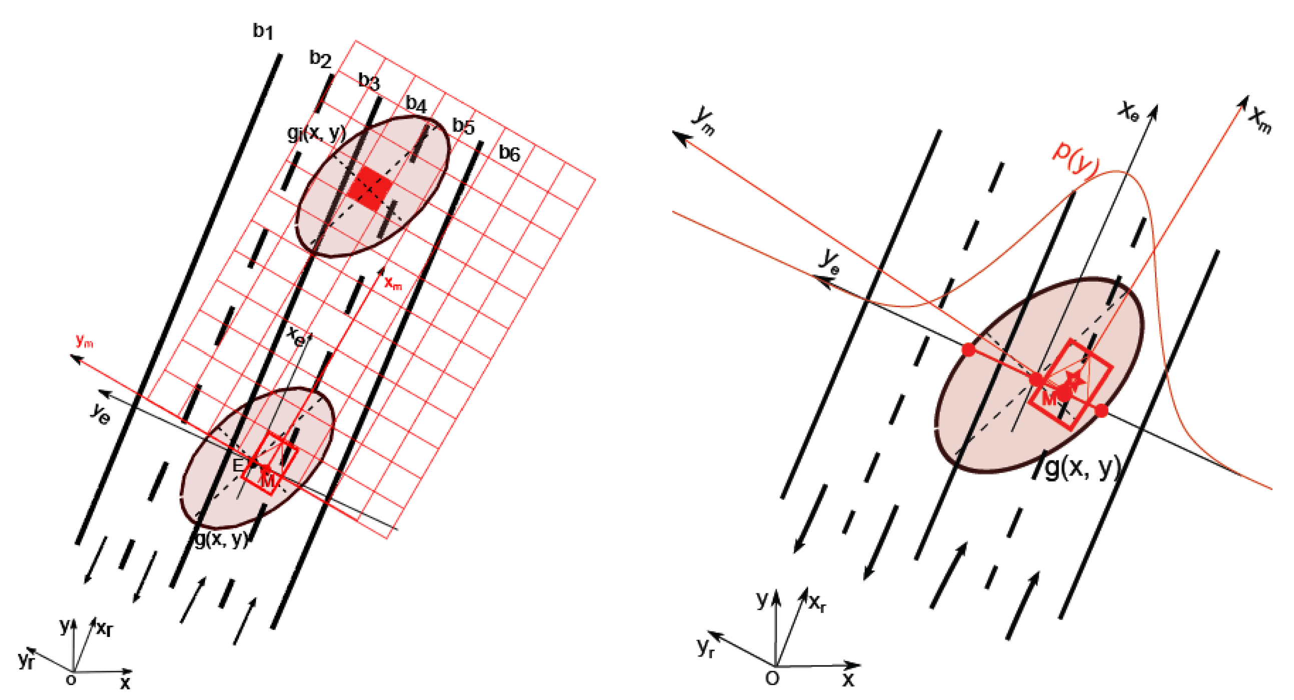
The cooperation between vehicles and with the infrastructure will be exploited in order to improve the safety of each vehicle, and in specific cases of complex resolution, with the aim of disbanding situations that today are unsolvable for an artificial decision system.

Motion planning architecture

- This thesis proposes a motion planning architecture for autonomous vehicles in which the uncertainty and heterogeneity in sensory information is taken into account. The architecture aims at limiting the search space to the region where the optimal solution is likely to exist, while keeping a high degree of reactivity.

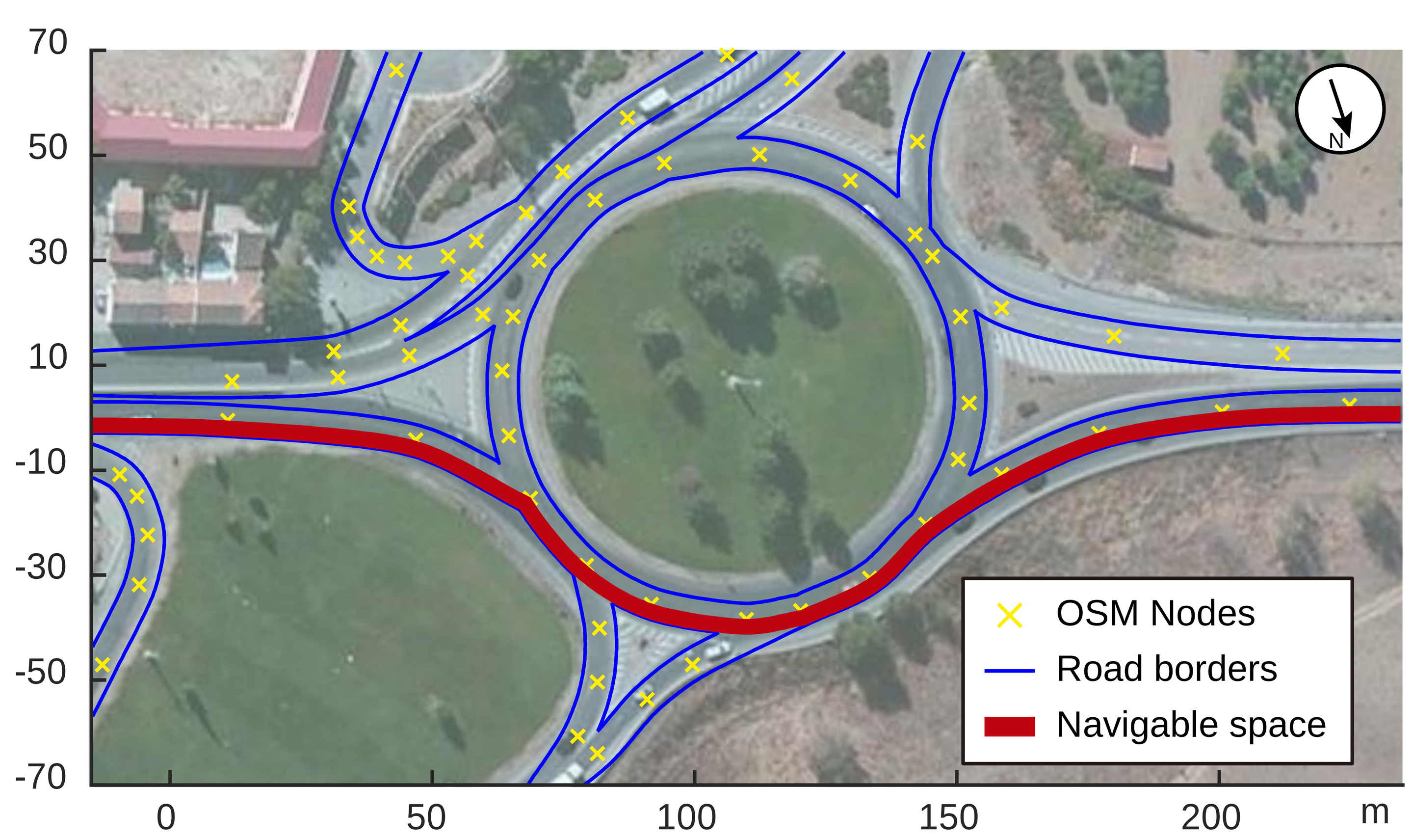


- To cope with uncertainty in pose estimation an occupancy grid is used. Moreover, the grid not only represents obstacle information [1] but also it is employed to propagate the vehicle pose estimation over the grids cells [2].



Pose uncertainty [2]

- A method for extracting information from OpenStreetMap and approximate the boundaries of the vehicles navigable space has been developed.
- An efficient and accurate polynomial-based map representation has been designed and implemented for trajectory planning: Straight segments are replaced by 3rd order Bézier curves.



Optimal path planning

- Requirements: (i) it must be comfortably driven by the vehicle, (ii) it must be contained in the admissible navigable space and avoid static obstacles.
- Goal: final trajectory from the current pose of the vehicle to the destination pose through a C^2 continuous path → concatenated cubic Bézier curves C_j.

- Optimization problem:

$$\min_{x} \quad J(x)$$
$$\text{subject to} \quad l_b \leqslant x \leqslant u_b$$
$$x = [b\ d_{long}\ d_{lat}],\ b \in 0,1$$
$$d_{long}, d_{lat} \in \mathbb{R}^{n-1}$$

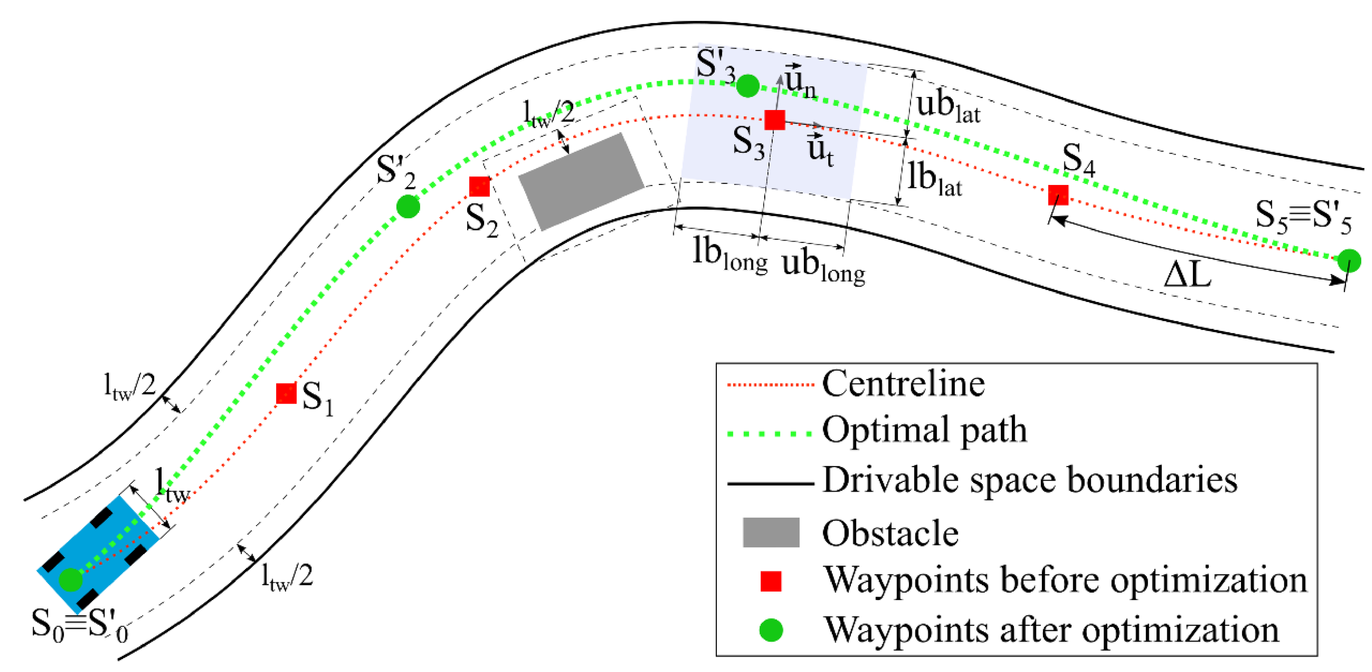
$$J = \sum_{i=1}^{n} \left(\int_0^{s_i} (\dot{\kappa}_i^2 + \omega \ddot{\kappa}_i^2)\, \mathrm{d}s \right) + h$$

$$\kappa = \frac{\dot{x}\ddot{y} - \dot{y}\ddot{x}}{(\dot{x}^2 + \dot{y}^2)^{\frac{3}{2}}}$$

$$h = \begin{cases} 0 & \text{if path is within boundaries} \\ \infty & \text{if boundaries/obstacle collision} \\ \infty & \text{if } k_{max}^p \geq k_{max}^v \end{cases}$$

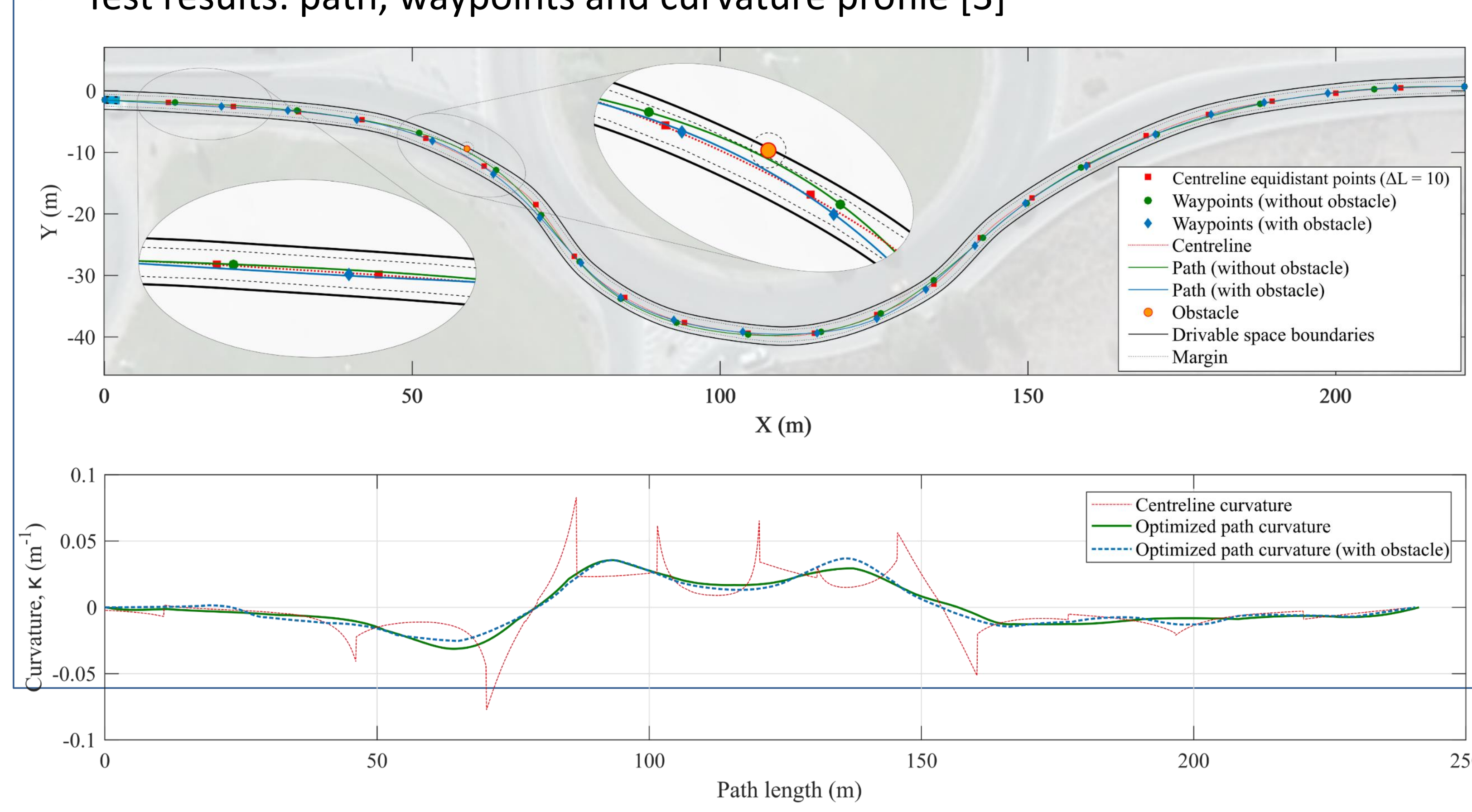
- It is a is a mixed-integer non-linear programming (MINLP) problem.
- We use Non-linear Optimization by Mesh Adaptive Direct Search (NOMAD)
- The optimal set of waypoints is then computed using

$$S_i' = S_i + d_{long_i}\vec{u}_{t_i} + d_{lat_i}\vec{u}_{n_i}$$



Path optimization scheme

- Test results: path, waypoints and curvature profile [3]



Concluding remarks

- The motion planning architecture allows a risk inference stage, allowing motion planning systems capable of integrating uncertainty and heterogeneity in sensory information, while structurally incorporating the possibility of learning from complex and unpredictable situations
- A novel smooth path planning approach for autonomous driving in urban environments using OpenStreetMaps is proposed in this thesis.
- An automatic procedure to extract information from OSM as well as a path planning algorithm have been developed to generate comfortably driven paths while avoiding obstacles. The path planning stage comprises a MINLP optimization that finds the most suitable position of intermediate waypoints to connect Bézier curves.
- The motion planning architecture is tested in simulation [4] and validated in a real scenario demonstrating the suitability of the whole path planning scheme

References

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